CARBON DIOXIDE FLUX MEASUREMENT DURING SIMULATED TILLAGE

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Abstract

Measurement of tillage effects often includes CO_2 flux from soil before and after tillage. Our objective was to create a device to measure CO_2 flux continuously before, during, and after a simulated tillage operation. We put an auger inside a chamber to till the soil while monitoring CO_2 flux. We tested three soil conditions. First, cores stored long-term produced large peaks immediately after tillage followed by a steady rate decay. Second, simulated tillage in a summer fallow field produced a more modest peak, a rapid return to pretillage rate, and then a gradual climb in CO_2 flux rate over the next 10 min. The third soil condition, having sterilized topsoil, produced a peak and then immediately returned to the pretillage flux rate. We conclude that continuous monitoring before, during, and after tillage will be important for proper interpretation of flux data.

Researchers studying the effects of soil disturbance on soil respiration or soil C dynamics often measure CO_2 flux. This is done in the laboratory in closed vessels, or in the field using chambers monitored by chemical CO_2 traps or infrared gas analyzers. In the field, chambers are put in place from 5 to 30 min following tillage (Reicosky and Lindstrom, 1993; Rochette and Angers, 1999; Ellert and Janzen, 1999). In laboratory studies, soil manipulation takes place in the open atmosphere, then the soil is placed into a closed system for CO_2 monitoring over time. When the measurements are started, the data generally show a rapidly falling flux rate, which presumably began to fall after reaching some undetermined higher flux rate. The amount of time from the beginning of tillage or soil manipulation to the start of flux measurement will necessarily have a large influence on the data and perhaps the interpretation of the data. To our knowledge no one has measured CO_2 release continuously during soil disturbance.

Cropping systems involving tillage sometimes produce less soil C storage than untilled systems. Explanations include tillage-induced increases in respiration due to newly available carbon substrates (Buyanovsky et al., 1986) or changes in O_2 supply and CO_2 levels. Other factors that are changed by tillage are convection and diffusivity at the soil–atmosphere surface (Buyanovsky and Wagner, 1983), which mediate the flux of CO_2 from the soil atmosphere to the aboveground atmosphere. Tillage causes a temporary increase in CO_2 efflux as soil pores equilibrate with a new concentration gradient.

The response of microbes to newly available carbon substrates produced by a tillage operation should be measurable as respiration, but the response may be confounded with other factors. Blet-Charaudeau et al. (1990) measured a lag of 2 d before bacterial populations responded to soil sieving, even though CO_2 evolution was highest at the first measurement (3 h after collection) and dropped off steadily thereafter. In contrast, Calderon et al. (2000) measured a decrease in respiration after tillage. Roberts and Chan (1990) and Franzluebbers (1999) both found that severe manipulation of soil before laboratory incubation had only a temporary effect on elevating CO_2 evolution. Sorting out the many factors involved in carbon dynamics of various soil conditions will require more than point measurements of CO_2 flux.

In this brief paper we report our experience with a closed dynamic chamber within which tillage can be simulated while continuously monitoring CO_2 flux with an infrared gas analyzer. Our objective was to determine if continuous monitoring allows additional measurement of data that would not be available using current techniques.

Materials and Methods

Flux Monitoring Device

A chamber similar in design to that of Rochette et al. (1997), including the provision of a mixing fan and vent tube, was built using PVC plastic pipe, 36 cm in diameter by 54 cm tall, with a total chamber volume of 58 l. The CO_2 level was monitored using an infrared gas analyzer (LI-COR 6200, LI-COR, Lincoln, NE) at a flow rate of 1000 μmol s^{-1}. The chamber diameter was reduced to 20 cm at the bottom, so that the chamber would fit on top of 20 cm i.d. PVC collars placed in the ground, or on the top of 20 cm intact soil cores. The fan speed was set as low as possible while still producing rapid mixing within the chamber, as indicated by a quick ($<$5 s) response to changes in CO_2 flux. This response time was tested by injecting CO_2 gas. The 6-mm diameter by 170 cm long vent tube prevented a pressure difference from developing between the inside and outside of the chamber. Effects of factors such as fan speed or chamber size were not explored extensively because our goal was to test the idea of continuous monitoring and not to make absolute quantitative estimates.

The chamber was unique in that a tillage tool could be operated inside the chamber while making continuous CO_2 flux measurements. A 13-mm diameter steel drill rod, long enough to reach from outside the top of the chamber to 15 cm deep into the field soil or soil core, entered the chamber top through a gas-tight fitting. A flat blade about 4 cm wide by 18 cm long and 5 mm thick was welded to the bottom end of the drill rod. The ends of this blade were twisted slightly to

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create a propeller-shaped digging tool. To simulate tillage, the rod was turned by an electric motor at 500 rpm and the blade lowered into the soil. Tillage to a 15-cm depth took 5 to 10 s and completely pulverized the surface soil.

Soils

The device was tested on three soil conditions. The conditions were chosen because they were expected to produce different CO_2 flux responses to tillage. The first was soil without inputs or disturbance for >1 yr. It was tested as intact soil cores held at two different temperatures. The second soil condition was a field in conventionally tilled summer fallow. The third soil condition was in the same summer fallow field, but with sterilized surface soil.

Intact Cores

Twelve intact soil cores, 20 cm in diameter and 60 cm deep, were collected inside PVC tubes from a field previously cropped to wheat, which had been bare of vegetation for >1 yr. The Walla Walla silt loam (coarse, silty, mixed mesic Typic Haploxeroll) soil was moist (−0.1 to −0.3 MPa) at collection and remained moist throughout the measurements. Half of the cores were maintained at 6 to 7°C and the others allowed to remain at room temperature (20°C) for several weeks after core collection. These temperatures were chosen because facilities were readily available and the two temperatures were expected to produce substantial differences in biological activity. To measure the effect of tillage on CO_2 flux rate, the tillage chamber was placed on a core and readings were taken continuously for several minutes. Then the simulated tillage operation was performed inside the chamber to a depth of approximately 15 cm. Flux rate monitoring continued for up to 1 h after tillage.

Field Measurements

For the field measurements, four 20 cm i.d. PVC collars were driven 10 cm into the surface of a field in the summer fallow cycle of a winter wheat–summer fallow rotation. The soil type was the same as that of the cores described above. The field had a thin crust caused by very light rains on the otherwise thoroughly pulverized dust mulch. The collars were in place from 3 to 10 d before CO_2 measurement. To make the measurements, we attached the chamber to the top of the collar, took pretillage measurements for several minutes, performed the simulated tillage to a 15-cm depth, and continuously monitored CO_2 for another 20 min or more. The surface of this conventionally tilled summer fallow was air-dried to about a 5-cm depth, gradually gaining moisture to approximately −0.2 MPa at 15 cm. Soil temperatures at a 10-cm depth ranged from 21 to 36°C, depending on the day and time of measurement.

After completion of measurements at two of the collars, the tilled soil within the collars was removed to a 15-cm depth and the remaining hole covered lightly with plastic. The soil was autoclaved at 120°C and 1 kg cm^{-1} for 45 min and then again for 15 min 3 d later. In one case the autoclaved soil was aired briefly and then returned to its original collar. Carbon dioxide flux measurements (including a second tillage) started immediately. In the second case, the autoclaved soil was returned to its original collar, covered loosely, and allowed to equilibrate with the below- and aboveground atmospheres for 24 h before starting flux measurements.

Since the measurements are continuous, the control for each measurement is provided by the period of measurement before soil disturbance. This predisturbance CO_2 flux rate would be expected to continue unchanged throughout the measurement period if disturbance had not occurred.

In a closed chamber, CO_2 concentration builds up above ambient levels, so the possible effect of feedback inhibition was checked by purging or scrubbing CO_2 from the chamber to bring it back down near ambient levels. None of the purges were followed by an increase in flux, which would have indicated feedback inhibition.

Results and Discussion

We were successful in measuring three different responses to simulated tillage, which would not have been observed without continuous measurement. These responses will be described briefly, followed by some tentative relationships to current soil CO_2 flux theory. The reader is reminded that these examples were not intended to answer specific CO_2 flux questions, but to test the idea that continuous measurement could be a valuable tool.

Intact Cores

Tillage of intact cores at two temperatures produced CO_2 flux responses that were very similar in shape but different in magnitude (Fig. 1). The ratio of average

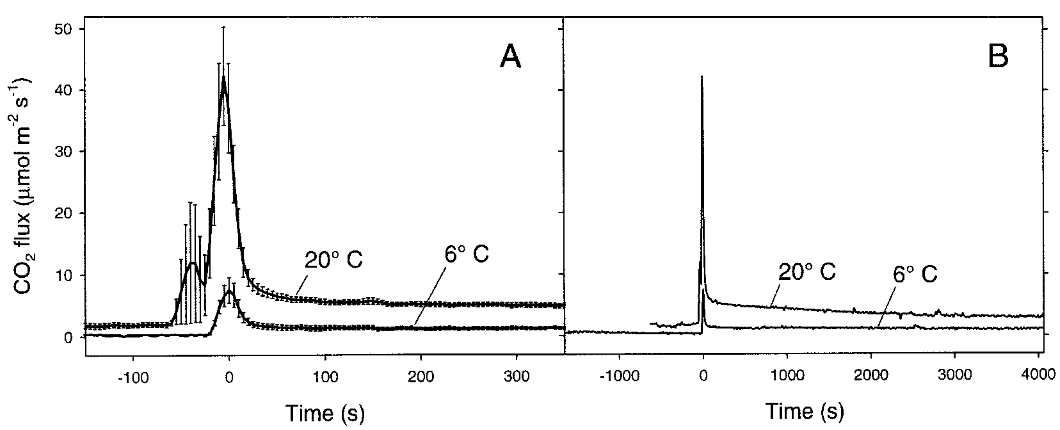

Fig. 1. Average CO_2 flux of six warm and six cold intact soil cores before, during, and after tillage. A) Detail (covering approximately 8 minutes) of tillage peaks showing standard error of the mean, and B) full duration (over 90 minutes) of measurements. The peaks were aligned (time = 0) to allow averaging. The first rise in flux rate occurred immediately after the start of tillage. The flux rates are calculated from 16 s rolling averages containing five 3.2 s intervals.

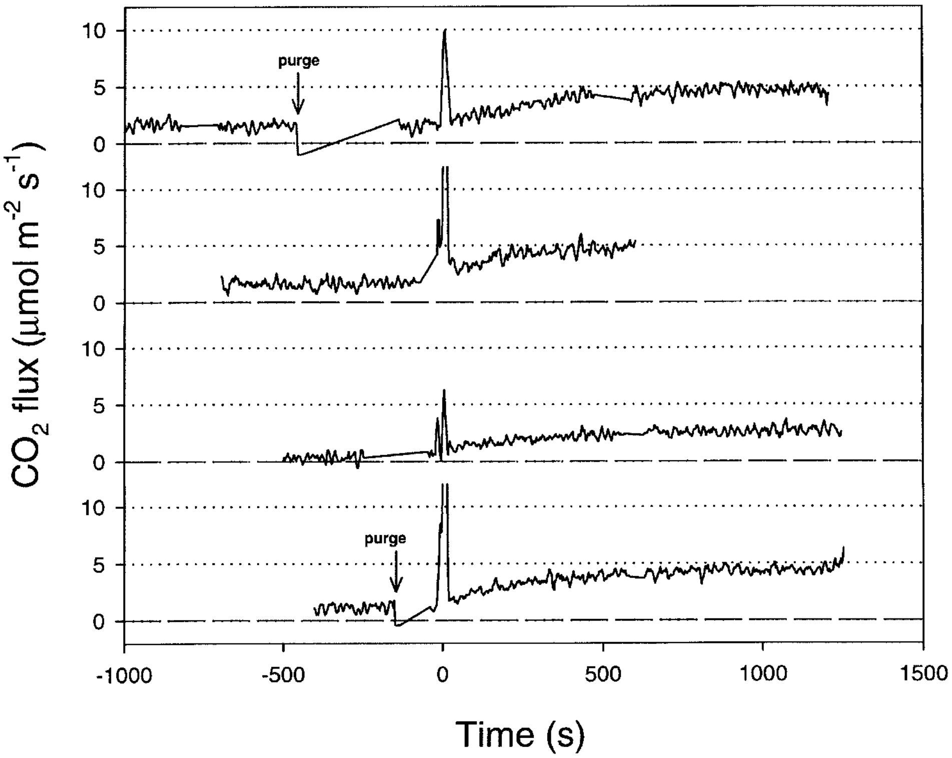

Fig. 2. Field measurements of CO_2 flux from four individual collars in the field before, during, and after tillage. Arrows indicate where the elevated CO_2 concentration in the chamber was reduced to ambient levels to check for feedback inhibition. Maximum CO_2 concentration in the chamber ranged from 390 to 440 µmol mol^{-1}. Straight lines indicate gaps in monitoring. The small scale instability of flux measurements reflects variability in flow rate measurements.

flux rate at 20°C to average flux rate at 6°C was 5:1 before tillage and 4:1 after tillage. This CO_2 flux response to temperature has been reported by others (MacDonald et al., 1995; Winkler et al., 1996). The double peak on the 20°C curve was very consistent but remains unexplained, and we assume it has to do with an artifact of the measuring equipment. It only occurred during the approach to extremely high flux rates, and can be reproduced without soil in the lab using the sudden introduction of high CO_2 flux. Both the cold and warm cores demonstrated a release of CO_2 on tillage, followed by an elevated but gradually declining flux rate over the next hour.

The flux response of these intact cores, which had not received carbon inputs for >1 yr, might indicate a mostly abiotic response to tillage. Loosening the surface

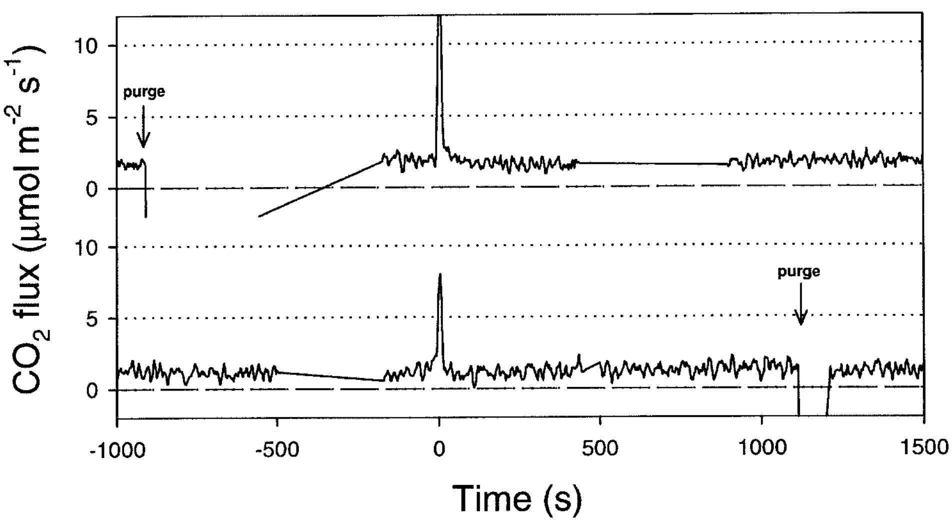

Fig. 3. Two flux measurements made after tilled surface soil had been sterilized and returned to the collar. In the top graph, surface soil was returned and measurements started immediately. In the bottom graph, surface soil was returned and allowed to equilibrate for 24 h. Arrows indicate where the elevated CO_2 concentration in the chamber was reduced to ambient levels to check for feedback inhibition. Maximum CO_2 concentration in the chamber ranged from 390 to 440 µmol mol^{-1}. Straight lines indicate gaps in monitoring. The small scale instability of flux measurements reflects variability in flow rate measurements.

soil released trapped soil atmosphere, resulting in the release of high CO_2 concentrations. The continued, but gradually declining, elevated flux could be caused by outgassing of soil pore space as it approaches a new equilibrium with the aboveground atmosphere.

Field Measurements

The four replicates of the field measurement produced similar results (Fig. 2), differing mostly in tillage-peak height and posttillage flux levels. All four demonstrated a short duration spike in CO_2 flux during tillage followed by a gradual rise in flux during the next 20 or more minutes. The gradual rise in CO_2 flux may be due to an increase in respiration by organisms. This soil was in the process of mineralizing residues plowed into the soil 2 mo before.

Field Measurements with Sterile Topsoil

When topsoil was removed, sterilized, and replaced, the predisturbance flux rate and peak immediately following tillage were similar to the nonsterilized soil condition (Fig. 3). Immediately following the peak, however, the flux rate dropped to the predisturbance rate and stayed there for the duration of the measurement. It is presumed that the main source of CO_2 flux during the measurements would be the subsurface soil, since microbial activity in the sterilized surface soil should have been minimal.

Conclusion

Our flux measurements, while not a thorough test of the device's promise or limitations, give examples of responses to soil disturbance which could not be detected by noncontinuous methods. Two of these examples produced the same tillage-induced, elevated CO_2 flux typically measured by other researchers, but our measurements detected two very different responses immediately following the soil disturbance. These results demonstrate the potential of continuous monitoring as an aid in interpretation of flux changes. Another benefit of measuring flux during tillage is the ability to calculate total CO_2 balances to estimate soil atmosphere CO_2 changes caused by tillage.

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